

CLAIMS

What is claimed is:

- 1 1. A method for operating a fuel cell system in
2 sub-freezing ambient temperatures, wherein the
3 system includes a stack of PEM fuel cells including
4 at least one cooler for carrying antifreeze through
5 the stack to remove heat from the stack, each cell
6 including a water transport plate and having water
7 flow passages therethrough, the method including the
8 steps of: a) draining any liquid water from the
9 cell water flow passages upon or after the previous
10 shut-down of the stack before freezing can occur,
11 and thereafter b) starting-up the stack by directing
12 fuel and oxidant reactants into the cell and
13 connecting a load to the stack; c) using heat
14 produced by the stack to increase the operating
15 temperature of the stack to at least 0°C to melt any
16 ice within the cells; and, d) upon the stack
17 operating temperature reaching at least 0°C,
18 circulating anti-freeze through the stack coolers to
19 maintain the operating temperature of the stack low
20 enough to prevent cell dry out for at least as long
21 as liquid water does not circulate through the water
22 flow passages.
- 1 2. The method according to claim 1, wherein the
2 fuel cell system includes a water circulation system
3 for circulating water through the water flow
4 passages of the cells, the water circulation system
5 including a water accumulator; wherein the step of
6 draining liquid water from the water flow passages
7 includes draining substantially all liquid water
8 from the water circulation system.
- 1 3. The method according to claim 1, wherein the
2 antifreeze circulation is not started until the
3 operating temperature of the stack is at least 10°C.

- 1 4. The method according to claim 1, wherein the
2 antifreeze circulation is not started until the
3 operating temperature of the stack is at least 30°C.
- 1 5. The method according to claim 4 wherein during
2 stack operation without water circulating within the
3 water flow passages of the cells, the operating
4 temperature of the stack is maintained at no more
5 than about 40°C.
- 1 6. The method according to claim 2 including,
2 during operation after start-up, the step of
3 collecting cell product water within the accumulator
4 and, after a sufficient amount of water has been
5 collected within the accumulator to enable
6 circulation of water through the water flow
7 passages, circulating the water through the water
8 flow passages and allowing the stack operating
9 temperature to increase to normal operating levels.
- 1 7. The method according to claim 1, wherein the
2 fuel cell system includes a water circulation system
3 for circulating water through the water flow
4 passages of the cells, the water circulation system
5 including a water accumulator, wherein upon start-up
6 of the stack the water circulation system has water
7 within the accumulator, wherein the step of starting
8 up the stack includes melting any frozen water
9 within the accumulator and, when sufficient liquid
10 water is available within the water circulation
11 system, circulating liquid water through the cell
12 water flow passages.
- 1 8. A method for operating a fuel cell system when
2 ambient temperatures may be below the freezing point
3 of water, wherein the fuel cell system includes a
4 stack of fuel cells, each cell including a proton
5 exchange membrane sandwiched between an anode water
6 transport plate on the anode side of the membrane a
7 cathode water transport plate on the cathode side of

8 the proton exchange membrane, an anode catalyst
9 layer adjacent the anode side of the proton exchange
10 membrane, a cathode catalyst layer adjacent the
11 cathode side of the proton exchange membrane, and a
12 cooler separating at least one pair of adjacent
13 cells in the stack for carrying anti-freeze through
14 the stack, the cooler being connected to an anti-
15 freeze circulating system, each cell also including
16 water flow passages therewithin connected to a water
17 circulating system, said method comprising the steps
18 of (a) starting the fuel cell system without water
19 within said water flow passages, including flowing
20 air over the cathode side of the proton exchange
21 membrane, flowing fuel reactant gas over the anode
22 side of the proton exchange membrane, and connecting
23 the load to the stack, (b) operating the stack
24 without circulating antifreeze coolant through the
25 coolers at least until the heat generated by the
26 stack raises the stack temperature above 0°C, and,
27 thereafter, (c) circulating anti-freeze through the
28 coolers to maintain the stack at below normal
29 operating temperatures for the period of time that
30 no liquid water circulates through the water
31 circulation system, said below normal stack
32 temperatures being low enough to prevent cell dry
33 out during said period of time, and (d) upon shut
34 down of the system, drain all liquid water from the
35 water flow passages before it freezes.

1 9. The method of claim 8, wherein said antifreeze
2 circulation is not started until frozen water, if
3 any, within the stack has started to melt.

1 10. The method of claim 8, wherein said antifreeze
2 circulation is not started until all frozen water,
3 if any, within the stack has melted.

1 11. The method according to claim 1, wherein sub-
2 freezing temperatures are expected during a selected

3 period of the year, and wherein the fuel cell system
4 includes a water circulation system for circulating
5 water through the water flow passages of the cells,
6 the water circulation system including a water
7 accumulator, and wherein prior to said step (a), (i)
8 draining all liquid water from the accumulator and
9 keeping it empty for said selected period of the
10 year; and (ii) preventing water from circulating
11 through the water flow passages and water
12 circulation system for said selected period of the
13 year, wherein steps (a) through (d) are done
14 throughout said selected period of the year without
15 water circulating through the water flow passages.

1 12. The method according to claim 9, wherein the
2 below normal temperatures of step (c) are no greater
3 than 40°C

1 13. The method according to claim 11, wherein
2 antifreeze circulation is not started until the
3 operating temperature of the stack is at least 10°C.

1 14. The method according to claim 11, wherein
2 during stack operation without water circulating
3 within the water flow passages of the cells, the
4 operating temperature of the stack is maintained at
5 no more than about 40°C.

1 15. The method according to claim 2, wherein
2 product water from operation of the stack is
3 accumulated within the accumulator until sufficient
4 liquid water has accumulated in the water
5 circulation system to enable circulation of that
6 water through the water flow passages; and,
7 thereafter, initiating and continuing circulation of
8 the accumulated water through the water flow
9 passages and circulation system and allowing the
10 temperature of the stack to rise to normal operating
11 temperatures.

- 1 16. The method according to claim 8, wherein
2 circulation of the anti-freeze is initiated only
3 after the stack temperature has increased to at
4 least 10°C.
- 1 17. The method according to claim 8, wherein at
2 some time before shut-down the water circulation
3 system begins to circulate water through the water
4 flow passages, at which time the temperature of the
5 stack is allowed to rise to normal operating
6 temperature.
- 1 18. A method of shutting down and restarting a
2 fuel cell system comprising a stack of proton
3 exchange membrane fuel cells wherein the stack, at
4 or after a system shut-down and prior to the next
5 system start-up, is exposed to below freezing
6 temperatures, and wherein each of said cells
7 includes a fuel reactant gas flow field on an anode
8 side of the cell, an oxidant reactant gas flow field
9 on a cathode side of the cell, a cooler separating
10 at least one pair of adjacent cells in the stack to
11 remove heat from the stack, the stack also including
12 water flow passages therewithin connected to a water
13 circulating system for circulating water through the
14 water flow passages, including the steps of (a)
15 shutting down the fuel cell system while it is
16 generating electrical power by disconnecting the
17 stack from its load, halting the flow of reactants,
18 halting any circulation of water through the water
19 passages, and draining the liquid water from the
20 water passages; and, thereafter, (b) initiating
21 start-up of the system by (i) flowing air to the
22 oxidant reactant gas flow fields and fuel reactant
23 gas to the fuel reactant gas flow fields, (ii)
24 connecting the load to the stack, and (iii)
25 operating the stack at part power at least until the
26 stack temperature is above 0°C and any frozen water

27 within the stack is melted; and, thereafter (c)
28 initiating and maintaining the circulation of anti-
29 freeze through the cooler to maintain the stack
30 temperature at below normal stack operating
31 temperatures at least until the water circulation
32 system is able to circulate water through the water
33 passages, wherein such below normal temperatures are
34 low enough to prevent cell dry out; and, thereafter,
35 (d) initiating and continuing circulation of water
36 through the water passages and circulation system
37 and allowing the temperature of the stack to rise to
38 normal operating temperatures until the system is
39 shut down.

1 19. The method of claim 18, wherein the step of
2 initiating circulation of anti-freeze is done after
3 the stack temperature has increased to at least
4 10°C, and the below normal temperatures of step (c)
5 are no greater than about 40°C.

1 20. The method of claim 18, wherein the step (a)
2 of shutting down the stack includes draining the
3 liquid water from the entire water circulation
4 system.

1 21. The method of claim 6, wherein the water
2 circulation system includes a water accumulator for
3 holding water used for water circulation through the
4 water flow passages of the cells, and wherein upon
5 and during shut-down of the stack the water
6 accumulator is not drained, and step (b) includes
7 melting frozen water in the accumulator, if any,
8 after initiating start-up, by using energy generated
9 by the stack.
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